GROUND REACTION FORCE OF THE HIP, KNEE AND ANKLE JOINTS IN ADOLESCENT IDIOPATHIC SCOLIOSIS: COMPARISON BETWEEN NORMAL POPULATIONS

By

DR. PREMA SIVALINGARAJAH

DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF MEDICINE (ORTHOPAEDICS)

SCHOOL OF MEDICAL SCIENCES
UNIVERSITI SAINS MALAYSIA

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMNS

AIS	Adolescent idiopathic scoliosis
CSL	Central sacral line
CSVL	Central sacral vertical line
GRF	Ground Reaction Force
JRF	Joint Reaction Force
LIV	Lower Instrumented Vertebra
SRS	Spine Research Society
UIV	Upper Instrumented Vertebra
USM	Universiti Sains Malaysia

KAJIAN BERKAITAN DENGAN DAYA YANG BERTINDAK KE ATAS SENDI PELVIS, SENDI PINGGUL DAN SENDI LUTUT DI KALANGAN PESAKIT SKOLIOSIS IDIOPATHIK

ABSTRAK

Latar Belakang

Scoliosis idiopathic remaja (AIS) adalah kes yang agak biasa ditemui dalam klinik ortopedik. Ia boleh mengubah pergerakan manusia. Setakat ini, tiada laporan lagi tentang perbandingan *GRF* antara pesakit yang menerima rawatan sebelum dan selepas pembedahan. Data ini dijangka memberi bukti klinikal tentang bagaimana scoliosis boleh mempengaruhi *GRF* yang dipikul oleh sendi.

Matlamat dan Objektif

Kajian ini bertujuan untuk menubuh dan membanding GRF pada tiga sendi utama anggota bawah badan, yang memikul berat badan semasa gaya berjalan normal, dalam kalangan kumpulan orang biasa, kumpulan orang dengan scoliosis idiopathic, dan kumpulan orang dengan scoliosis idiopathic yang telah menerima rawatan fusion segmen tulang belakang.

Kaedah

Peserta kajian telah diambil dari Hospital Raja Perempuan Zainab II dan Hospital Universiti Sains Malaysia. Kedua-dua hospital ini adalah hospital rujukan bagi kes-kes tulang belakang di Kelantan, Malaysia. Sebanyak 41 peserta kajian yang memenuhi kriteria kajian telah diambil, iaitu kumpulan kawalan tanpa scoliosis (n = 14), kumpulan

scoliosis tanpa rawatan fusion segmen tulang belakang (AIS) (n = 14), dan kumpulan AIS yang telah menerima rawatan fusion segmen tulang belakang (n = 13). Analisis gaya berjalan telah dilakukan di Unit Sains Sukan, Pusat Pengajian Sains Kesihatan, USM, yang dilengkapi dengan sistem optik yang terdiri daripada enam kamera digital resolusi tinggi untuk menangkap gerakan. Nilai-nilai ini telah dihitung semasa berjalan di atas platform gaya berjalan atas plat daya.

Keputusan

Profil daya GRF pada tiga paksi mengikut empat fasa berjalan bagi tiga kumpulan kajian telah ditubuhkan. Terdapat satu corak yang ketara diperhatikan pada GRF paksi-X dan paksi-Z mengikut empat fasa berjalan pada tiga sendi di antara tiga kumpulan kajian. GRF adalah pada garis dasar semasa fasa mogok tumit, kemudian ia meningkat pada pendirian awal dan pertengahan pendirian, dan akhirnya GRF menurun semasa fasa kaki angkat dan terus turun kembali kepada garisan dasar. Corak yang sama juga didapati pada GRF paksi-Y mengikut empat fasa berjalan pada sendi lutut dan tumit, tetapi tidak untuk sendi pinggul. Dalam perbandingan antara kumpulan, tidak ada perbezaan yang signifikan didapati dalam GRF pada tiga paksi pada tiga sendi kaki antara kumpulan AIS tanpa rawatan fusion segmen tulang belakang dan kumpulan normal. Tidak ada perbezaan yang signifikan juga didapati dalam GRF pada tiga paksi pada tiga sendi kaki antara kumpulan AIS dengan gabungan tulang belakang dan kumpulan normal. Tidak ada perbezaan yang signifikan dalam GRF paksi-X dan paksi-Z daripada tiga sendi antara kumpulan AIS tanpa rawatan fusion segmen tulang belakang dan AIS dengan gabungan tulang belakang. Namun terdapat perbezaan yang signifikan antara kumpulan AIS tanpa rawatan fusion segmen tulang belakang (44.00 ± 26.78) dan kumpulan AIS dengan rawatan fusion segmen tulang belakang (17.85 ±

17.21) pada GRF paksi-Y lutut kiri, di mana GRF adalah lebih tinggi (min perbezaan 26.15) dalam kumpulan AIS tanpa rawatan fusion segmen tulang belakang.

Kesimpulan

Scoliosis mempunyai kesan yang ketara ke atas GRF paksi-Y sendi lutut. Rawatan gabungan tulang belakang menyebabkan pengimbangan semula GRF paksi-Y sendi lutut, di mana GRF paksi-Y merupakan daya dorongan atau brek yang bertindak pada sendi.

GROUND REACTION FORCE OF THE HIP, KNEE AND ANKLE JOINTS IN ADOLESCENT IDIOPATHIC SCOLIOSIS: COMPARISON BETWEEN NORMAL POPULATIONS

ABSTRACT

Background

Scoliosis particularly Adolescent idiopathic scoliosis (AIS) is a relatively common condition seen in orthopaedic practice which can modify human locomotion. Thus far, no report yet on GRF comparison between pre- and post-operative treatment. This data is expected to give clinicians evidence based information on how scoliosis can affect all major weight bearing joints in term of its ground reaction force.

Aim and Objective

This study aimed to establish and compare the GRF on the three main weight-bearing lower limbs joints during a normal walking gait, among normal person, person with idiopathic scoliosis without spinal fusion, and person with idiopathic scoliosis with spinal fusion.

Method

Targeted subjects were recruited from Hospital Raja Perempuan Zainab II and Hospital Universiti Sains Malaysia, the two only referral hospitals for spinal cases in Kelantan, Malaysia. A total of 41 subjects fulfilling the recruiting criteria were recruited, namely control group without scoliosis (n=14), study group with scoliosis without spinal fusion

(n=14), and study group with scoliosis with spinal fusion (n=13). The gait analysis was done at Sport Science Unit, School of Health Sciences, USM, equipped with an optical motion capture system consisting of six high-resolution digital cameras. These values were computed during walking on the gait platform over the force plate.

Result

GRF profiles for the three study groups on the three axes of the three weight bearing lower limbs joints versus walking phase was established. There was a noticeable trend observed in changing of X-axis and Z-axis GRFs versus walking phase on the three joints among the three study groups. The GRF was at baseline during the heel strike phase, and then it increased during the early stance and mid stance walking phases, the GRF decreased during the toe off phase and further decreased back to the baseline. Similar trend was also found in Y-axis GRF versus walking phase on the knee and ankle joints, but not the hip joint. In group comparison, there were no significant difference in the GRF of the three axes of the three joints between AIS without spinal fusion and normal groups. There were also no significant difference in the GRF of the three axes of the three joints between AIS with spinal fusion and normal groups. There were no significant difference in the GRF of the X and Z axes of the three joints between AIS without spinal fusion and AIS with spinal fusion groups. There was a significant difference was found between the AIS without spinal fusion group (44.00±26.78) and group of AIS with spinal fusion (17.85±17.21) at left knee Y-axis GRF, in which the GRF is significantly higher by mean difference of 26.15 in AIS without spinal fusion group.

Conclusion

Scoliosis had significant effect on the knee joints Y-axis GRF. Spinal fusion results in rebalancing of the knee joint Y-axis GRF, in which Y-axis force reflects the propulsive or braking force in a joint.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Ground Reaction Force (GRF) is one of the contributing force acting towards a joint in the lower limb. It is equal in magnitude and opposite in direction to the force that the body exerts on the supporting surface through the foot transmitted to the ankle, knee an hip. GRF of the knee, hip joint and ankle can be altered by lower limb deformity, joint abnormality and spinal abnormality. These pathologies can transfigure the normal biomechanics of the human body hence causing changes in the joint reaction forces. Spine deformity particularly scoliosis is a relatively common condition seen in orthopaedic practice.

Adolescent idiopathic scoliosis (AIS) is a progressive growth disease that affects spinal anatomy, mobility, and left-right trunk symmetry. Consequently, AIS can modify human locomotion. Many patients with AIS require spinal fusion to control the spinal deformity as severe deformity can cause significant respiratory disturbance and back pain. The deformity can also affect patient's self-image and psychological perception.

The lower limbs, pelvis and spine are intimately interconnected and form a single body unit. Normal gait needs a mobile hip, knee and ankle together with pelvis and spinal segments. Even though spinal fusion does not involve the hip, knee and ankle joints directly, immobilization of significant number of spinal segments may indirectly affect biomechanics of the hip, knee and ankle joint unilaterally or bilaterally (Kramers-de Quervain *et al.*, 2004), as it may interfere the normal body movement during normal gait (Hopf *et al.*, 1998) and (Giakas *et al.*, 1996). Fusion of the spinal segment may restrict the normal 'orchestraic' movement of the segments and disturb the normal distribution of loads in the joints consequently may cause early degenerative changes of the joints.

An operative correction of a scoliotic curvature may bring about some changes in the biomechanical aspects, close to normal. Reduction of the muscle inefficiency and excessive energy expenditure (Mahaudens *et al.*, 2014) may also contribute to these changes. The question arises in this context of to what extent this new situation affects the pre-operative observed GRF compared to post-operative GRF. There is no similar study for comparison available in the literatures.

This study is expected to give clinicians evidence based information on how scoliosis can affect all major weight bearing joints in term of its ground reaction force. The alteration of these forces can give significant biomechanics implication in terms long term joint replacement therapy in adolescent idiopathic scoliosis patients.

CHAPTER 2

OBJECTIVES OF THE STUDY

2.1 Objectives of the Study

The objectives of this study include:

1. To measure the GRF of the hip, knee and ankle joints of a normal person (without spinal deformity)
2. To measure the GRF of the hip, knee and ankle joints of a person with adolescent idiopathic scoliosis on conservative treatment (without spinal fusion)
3. To measure the GRF of the hip, knee and ankle joints of a person with adolescent idiopathic scoliosis following spinal fusion
4. To compare the difference of GRF of the hip, knee and ankle joints in these three groups
5. To analyse the effect of scoliosis deformity (without fusion) on the GRF of the hip, knee and ankle joints versus a normal person
6. To analyse the effect of AIS with spinal fusion on the GRF of the hip, knee and ankle joints of a normal person
7. To analyse the effect of AIS with spinal fusion on the GRF of the hip, knee and ankle joints of scoliosis deformity (without fusion)

2.2 Hypothesis of the Study

1. Adolescent idiopathic scoliosis does not affect GRF of the hip, knee and ankle joints [Null hypothesis]
2. Spinal fusion does not affect the GRF of the hip, knee and ankle joints [Null hypothesis]

CHAPTER 3

LITERATURE RIVIEW

3.1 Definition of Scoliosis

Scoliosis is a medical condition in which a person's spine is curved from side to side. Although it is a complex three-dimensional deformity, on an X-ray viewed from the rear, the spine of an individual with scoliosis can resemble an "S" or "C", rather than a straight line. It is defined as a lateral curvature of the spine greater than 10 degrees (measured using the Cobb method on a standing radiograph) accompanied by vertebral rotation. Therefore it is a ‘C’ or ‘S’ deformity on coronal view, hypokyphosis in sagittal view and rotational deformity in rotational view. It is thought to be a multigene dominant condition with variable phenotypic expression (Reamy and Slakey, 2001).

3.2 Classification of Scoliosis

Scoliosis is typically classified as either congenital (caused by vertebral anomalies present at birth), idiopathic (cause unknown, sub-classified as infantile, juvenile, adolescent, or adult, according to when onset occurred), or secondary to a primary condition (Janicki and Alman, 2007). Secondary scoliosis can be the result of a neuromuscular condition (e.g., spina bifida, cerebral palsy, spinal muscular atrophy, or physical trauma), syndromes such as Chiari malformation / mesenchymal disorders like Marfan's syndrome or scoliosis in neurofibromatosis. Therefore, adolescent idiopathic scoliosis falls under Idiopathic scoliosis in children above 10 years of age with no secondary causes / normal vertebral anatomy.

Eighty percent or more of idiopathic scoliosis is of the adolescent variety. As it is often not possible to determine the age of onset, age at presentation/detection is more accurate. Thus, it is likely that there is overlap at the age two/three years infantile/juvenile interface and at the age nine/ten year juvenile/adolescent interface. It is much less likely at the infantile/juvenile interface because most infantile curves present in the first six months of life. The most common curves are left thoracic apex, and males are more frequently affected, whereas the most common juvenile curves are right thoracic apex and females are more frequently affected. This makes juvenile curve similar to adolescent curves. At the juvenile/adolescent interface, it is almost certain that many of the younger adolescents had their curves well established during their later juvenile years.

3.3 Epidemiology of Adolescent Idiopathic Scoliosis

Adolescent idiopathic scoliosis is present in 2 to 4 percent of children between 10 and 16 years of age (Reamy and Slakey, 2001). Adolescent idiopathic scoliosis is the single most common form of spinal deformity seen in orthopaedic practice. The incidence of small curves is rather high (2% of the population), whereas severe curves are much less common (< 0.1%), but we cannot always predict which curve will progress (Rinsky and Gamble, 1988). Epidemiological investigations have demonstrated that the incidence of idiopathic scoliosis is approximately 2% in patients with a Cobb angle of >10° and is approximately 0.3% to 0.5% among those with a Cobb angle of >20° while curvatures greater than 40° Cobb are found in less than 0.1% of the population. It is also very dependent on sex, being equal for curves of 6–10° but 5.4 girls to 1 boy for curves of 21° or more. The proportion of patients with adolescent idiopathic scoliosis who are in need of treatment is only 0.1% to 0.3% (Yagi *et al.*, 2014)

The main risk factors for curve progression are a large curve magnitude at the time of diagnosis, skeletal immaturity and female gender. The likelihood of curve progression can be estimated by measuring the curve magnitude using the Cobb method on radiographs and by assessing skeletal growth potential using Tanner staging and Risser grading (Reamy and Slakey, 2001). However, in only about 0.25% does the curve progress to the point that treatment is warranted (Asher and Burton, 2006).

3.4 Etiology of Adolescent Idiopathic Scoliosis

Idiopathic scoliosis is the most common form of lateral deviation of the spine with no clear underlying cause. The adolescent form accounts for the majority of cases of idiopathic scoliosis (Sabirin *et al.*, 2010). Understanding the cause of adolescent idiopathic scoliosis is important for elucidating its pathogenesis.

Adolescent idiopathic scoliosis can probably best be considered as a complex genetic trait disorder. There is often a positive family history but the pattern of inherited susceptibility is not clear. Current studies suggest that there is genetic heterogeneity. This indicates that multiple potential factors are acting either dependently or independently in its pathogenesis with possibilities that environmental factors may also be involved (Yagi *et al.*, 2014). Various theories have been postulated regarding the cause of idiopathic scoliosis, but none have been widely accepted.

De Sèze and Cugy (2012) proposed four main pathogenetic mechanisms: asymmetric bone growth dysregulation, susceptibility of bones to deformation, abnormal passive spinal system maintenance and disturbed active spinal system maintenance which can be organised into 2 large scale categories i.e. intrinsic factors (genetic factors, role of erect posture, spinal growth abnormalities, intervertebral disc abnormalities) and extrinsic factors (body asymmetry, connective tissue abnormalities, the role of erector spinae, hormonal factors, ole of melatonin, role of leptin and the autonomic nervous system, role of calmodulin, neuraxis growth abnormality with regard to the spinal cord, the role of the nervous system and of postural control).

3.5 Natural history of Adolescent Idiopathic Scoliosis

Knowledge of the natural history of adolescent idiopathic scoliosis has expanded greatly as it has become increasingly important to understand the nature of progression of the disease and its treatment effect along with its complications. Adolescent idiopathic scoliosis, if untreated does not increase mortality rate, even though on rare occasions it can progress to the >100° range and cause premature death. The rate of shortness of breath is not increased, although patients with 50° curves at maturity or 80° curves during adulthood are at increased risk of developing shortness of breath. Compared to non-scoliotic controls, most patients with untreated adolescent idiopathic scoliosis function at or near normal levels. They do have increased pain prevalence and may or may not have increased pain severity. Self-image is often decreased. Mental health is usually not affected. Social function, including marriage and childbearing may be affected, but only at the threshold of relatively larger curves (Asher and Burton, 2006).

Even though the natural history and long term treatment effects on adolescent idiopathic scoliosis have become a lot clearer, there are still many unknowns. Non-operative treatment effectiveness is limited and needs to be improved. Selection of adolescent patients for surgery is usually straightforward for major thoracic curves, but is much more problematic for double, lumbar and even thoracolumbar curves. This is because of the low level of instrumentation and arthrodesis required, and the resulting stress concentration on the remaining mobile lumbar motion segments. While ten to twenty-five years is a long term follow-up after treatment, the patients are still relatively young, 30 to 40 years of age.

3.6 Diagnosis of Adolescent Idiopathic Scoliosis

3.6.1 Presentation

The idea is to catch scoliosis early, start bracing aggressively and perform early surgery if indicated to prevent progression. Most scoliosis curves are initially detected on school screening exams, by a child's paediatrician or family doctor, or by a parent (Sabirin *et al.*, 2010). Some clues that a child may have scoliosis include uneven shoulders, a prominent shoulder blade, uneven waist, or the tendency to lean to one side. During school screening exams a 7 degree curve on scoliometer during Adams forward bending test is considered abnormal. 7 degrees correlates with 20^0 coronal plane curves. The diagnosis of scoliosis and the determination of the type of scoliosis are then made by a careful bone exam and an X-ray to evaluate the magnitude of the curve. If a scoliosis curve gets worse, the spine will also rotate or twist, in addition to curving side to side. This causes the ribs on one side of the body to stick out farther than on the other side (Burton, 2013). Severe scoliosis can cause back pain and difficulty breathing.

Clinical examination should rule out secondary causes of the scoliosis or associated anomalies. Severe pain, a left thoracic curve or an abnormal neurologic examination are signs and symptoms that point to a secondary cause for spinal deformity. An MRI is warranted to look for intraspinal lesion (Burton, 2013). Scoliosis does not hurt normally but in adult it hurts due to muscular strain. Pain is usually over the convex site.

3.6.2 Clinical Assessment

3.6.2 1 Clinical Features of Scoliosis

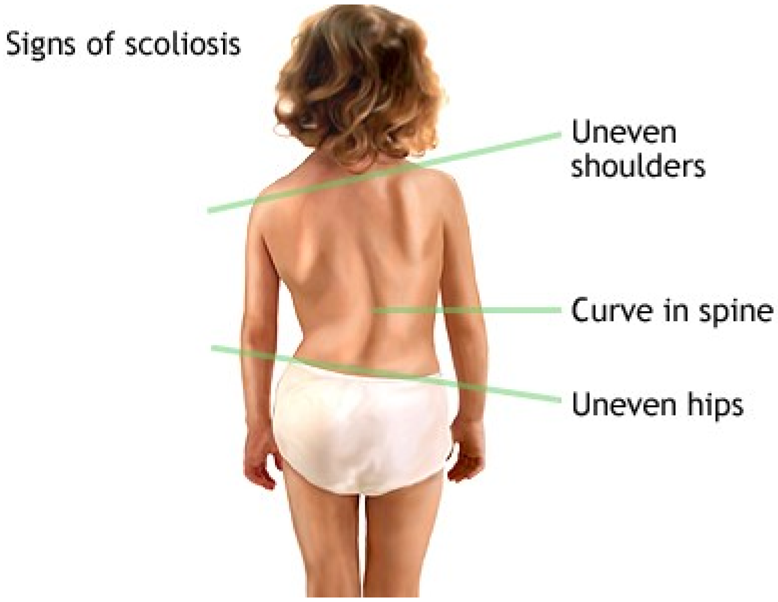


Figure 3.1 Clinical features of scoliosis

Note: Adapted from American Accreditation HealthCare Commission website

3.6.2 2 Differentiate from Postural and Structural Scoliosis

- Adam forward bending test – ask patient to assume diving position with feet together and knee extended. Structural curves persist when a person bends over, whereas postural curves disappear.

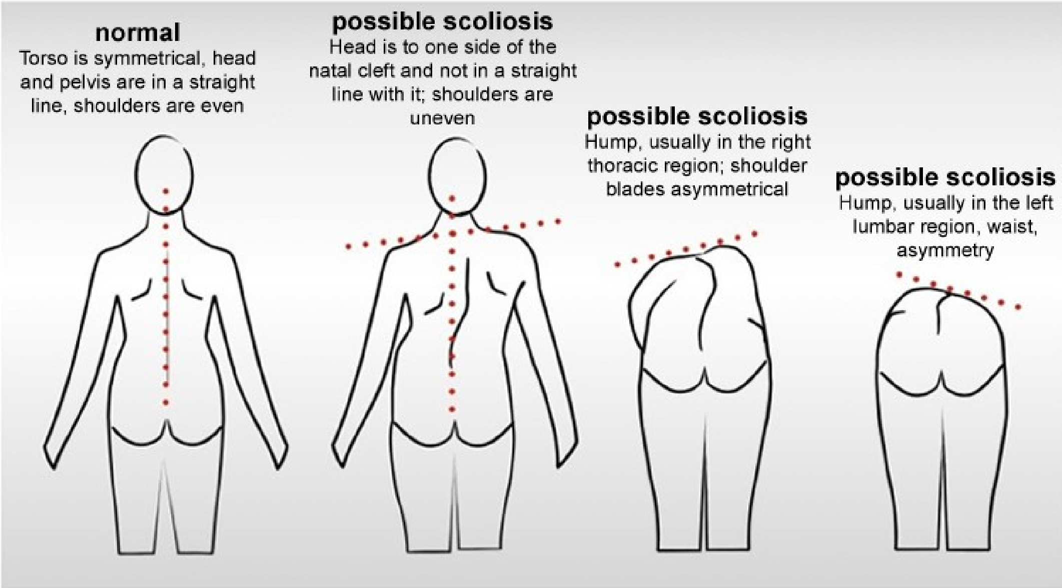


Figure 3.2 Adam forward bending test

Note: Adapted from Malcom Freedman, Orthotist & Prosthetist website

- Ask patient to sit and view the patient from behind – in postural scoliosis, due to the leg length discrepancy, the curve disappears when the patient sits as the pelvis is levelled. In structural scoliosis, the curvature remains visible when the patient sits.

3.6.2 3 Clinical Measurement of Scoliosis

3.6.2 3.1 Scoliometer

- Place the scoliometer and measure the angle at its maximum angle along the spinous process.
- The maximum thoracic and lumbar asymmetries are lnown as the "angle of trunk rotation" (ATR).
- ATR of 7° correlates with a Cobb angle of 20°.

Figure 3.3 Measurement of rib hump prominence using a scoliometer

Note: Adapted from Malcom Freedman, Orthotist & Prosthetist website

3.6.2 3.2 Plumb Line

- Patient standing in erect position.
- Identify the C7 spinous process.
- Place the plumb line.
- Read the amount of the body shift from the gluteal cleft.

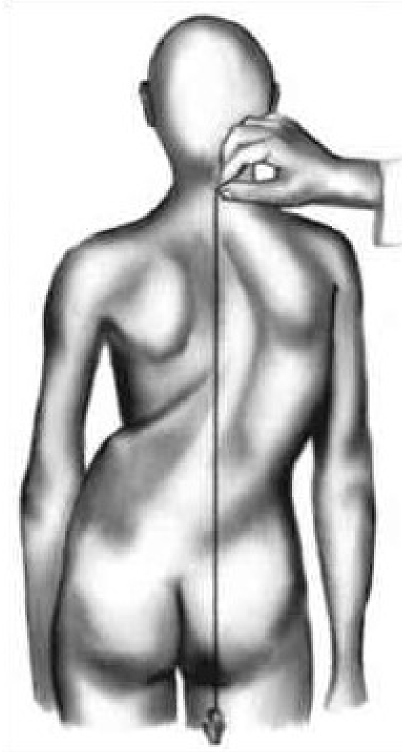


Figure 3.4 Measurement of plumb line

Note: Adapted from Doctor Steve Abel; Spinal Stabilisation website

Plumb line measurements give an idea on sagital balance and are predictors in spinal balance excursion. This eventually affects the balancing ability and gait pattern for patients with adolescent idiopathic scoliosis. Although AIS correction has historically focused on the coronal plane, sagittal parameters may be more important for motion than previously theorized (Paul *et al.*, 2014)

3.6.3 Imaging

3.6.3 1 Plain X ray

To objectively diagnose scoliosis the magnitude of the scoliosis curvature known as Cobb angle is measured on an AP view of whole spine with patient in standing position taken from a distance of 2 metres using a 14 x 36 inch cassette with hip and knee fully extended and feet together.

3.6.3 1.1 How to Measure Cobb Angle

Draw a line along the suspected end vertebrae. (Superior end plate of upper end vertebra and inferior end plate of lower end vertebra). Choice of end vertebra would be (b) and (e) as it is the most tilted in relation to the horizon. Cobb angle is x degrees.

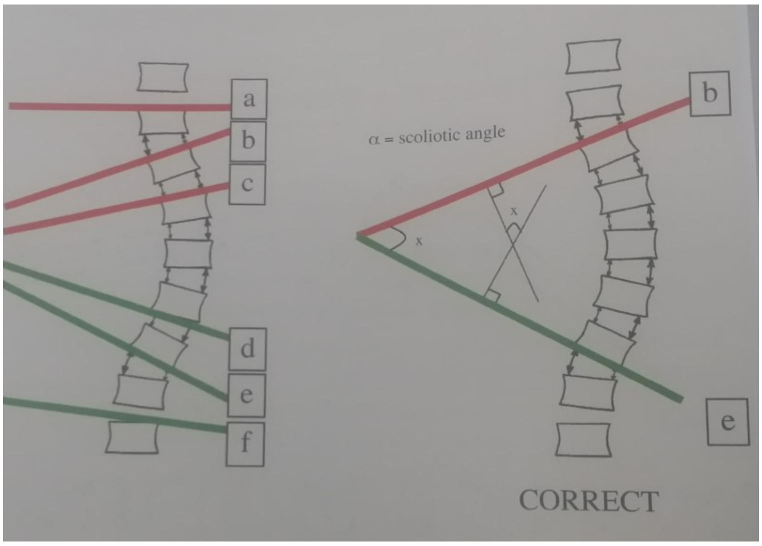


Figure 3.5 Correct method of Cobb's angle measurement

Note: Adapted from Stephen I, Esses JB, et al. Textbook of Spinal Disorders. Philadelphia: Lippincort Company; 1995, p. 272

3.6.3 1.2 Important Radiological Assessment of Scoliosis

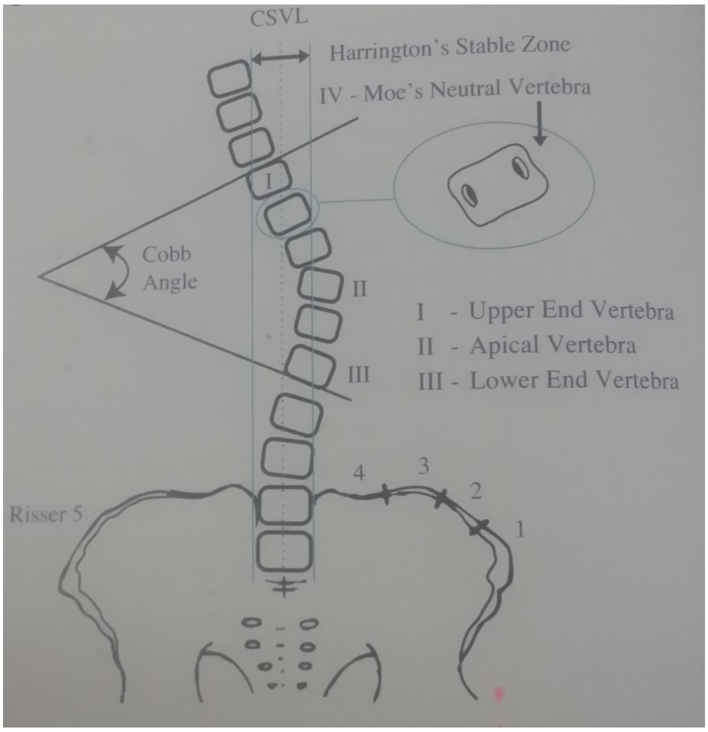


Figure 3.6 Types of vertebrae and important radiological markings in idiopathic scoliosis

Note: Adapted from Miller MD, Brinker MR, ed: Review of Orthopaedics, 3rd ed, Philadelphia, W.B. Sounders Company, 2000, p. 165.

- End vertebrae (I and III) – The vertebra that is most tilted in relation to the horizon.
- Apical vertebrae (II) – The vertebrae/ disc that is most laterally translated in relation to the central sacral vertical line (CSVL).
- Moe's Neutral vertebrae (IV) – A neutrally rotated vertebra evidenced by equidistance of pedicle from the spinous process.
- Stable Vertebrae – The vertebrae that falls within the stable zone of Harrington or most closely bisected by the Central Sacral Vertical Line (CSVL).
- Harrington's Stable Zone – Defined by two vertical lines drawn through the L5/S1 facets.

- CSVL – A vertical line in frontal radiograph that passes through the centre of the sacrum.
- CSL – A line intersecting the S1 spinous process and perpendicular to a line along the highest point of the posteriar iliac crest.
- Risser Sign – Evaluation of skeletal maturity by visualization of progressive ossification of iliac apophysis from lateral to medial direction.

<u>Special Radiographs for Scoliosis</u>

a. Whole spine erect anteroposterior radiograph
b. Whole spine erect lateral radiograph
c. Supine side bending radiograph of the whole spine to right and left
d. Fulcrum bending radiograph
e. Lower limb axis view

3.6.3 2 MRI

MRI should extend from posterior fossa to conus. Its purpose is to rule out intraspinal anomalies (Singhal *et al.*, 2013).

3.6.3 2.1 Indications for MRI

a. Non-idiopathic curve, eg. neuromuscular and congenital
b. Infantile/ Juvenile scoliosis
c. Abnormal curve pattern
    i. Right sided lumbar curve
    ii. Left sided thoracic curve
    iii. Unusual apical level

iv. Acute short angular curve

v. High thoracic apex (eg. Right T5)

d. Male

e. Excessive kyphosis

f. Painful curve

g. Neurological signs present, especially asymmetrical abdominal reflex

h. Rapid progression of Cobb angle

3.6.3 2.2 Lesions to Look for in the MRI

a. Craniocervical junction lesion

i. Arnold Chiari malformation

ii. Atlantoaxial pathalogy eg. Basilar invagination

b. Syringomyelia

c. Diastematomyelia

d. Tethered cord (low lying cord)

e. Spinal cord/ Brain tumours

A diagnosis of adolescent idiopathic scoliosis can be attained from history, physical examination and imaging. To facilitate our management process, a globally understood classification is used to standardise management protocol and easy communication and discussion on patients with adolescent idiopathic scoliosis

3.7 Classification for Adolescent Idiopathic Scoliosis

The use of classification schemes for radiographic evaluation of AIS is important for many reasons as stated below:

- Teaching tool for trainees

- A means of common communication between various scoliosis practitioners to have the ability to compare various treatments of similar curve pattern.
- To allow comparisons between various reports in the literature that describes new and potentially better ways of treating AIS.
- Method of recommending selective fusions of the spine when appropriate.

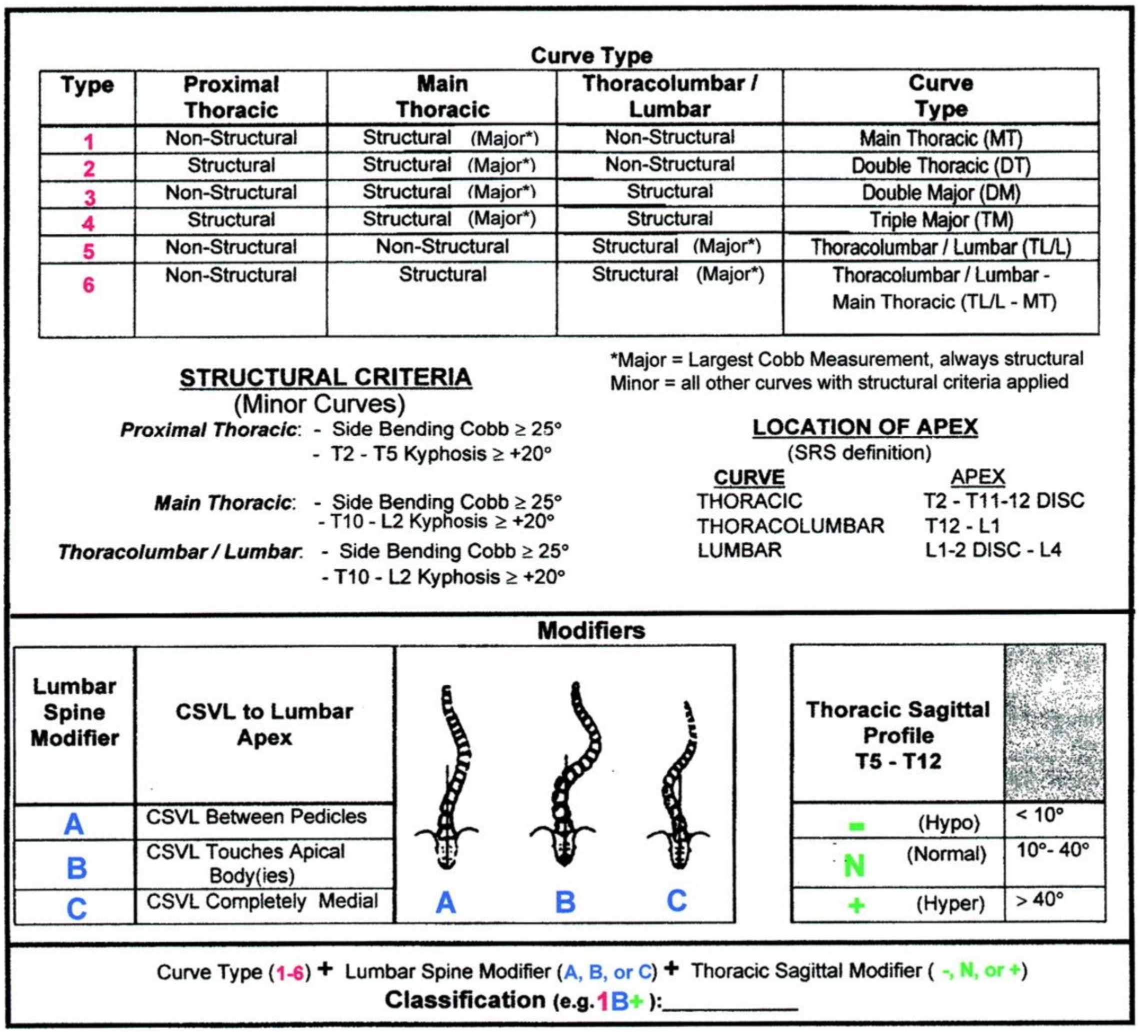


Figure 3.7 Lenke classification (Lenke *et al.*, 2003)

Note: Adapted from Lenke LG, Betz RR, Harms J, Bridwell KH, et al. Adolescent Idiopathic Scoliosis: A new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am, 83: 1169-1182, 2001

The system begins with an evaluation of each of the three major spinal column regions that may develop operative curves i.e. Proximal Thoracic (PT), Main Thoracic (MT) and Thoracolumbar/Lumbar (TL/L). The major curve is the one with largest Cobb measurement and that will always be included in the fusion of operative AIS. The minor curves are all other non-major curves present. One of the main debates in scoliosis surgery is whether to include those minor curves in the fusion or not. Minor curve structural criteria were established to help guide the surgeon in this decision making process. In the coronal plane, inflexibility on side bending $\geq 25^0$ in each of the 3 regions renders that region a structural minor curve. In addition, hyperkyphosis of 20 in the proximal thoracic (T2 – T5) region or the thoracolumbar junction (T10 – L2) renders either the PT region above and / or the MT or TL/L region below structural as well.

This system has designated 3 distinct lumbar curve patterns before surgery as lumbar mofiers A, B or C. The lumbar modifier is based on the position of the center sacral vertical line (CSVL) to the apex of the lumbar curve. For lumbar modifier A, the line falls between the pedicles of the lumbar spine up to the stable vertebra. . For lumbar modifier B, the line touches the apex of the lumbar curve. . For lumbar modifier C, the apex of the lumbar curve falls completely off the midline depicting a curve with complete apical translation off the CSVL. In this context, a true selective thoracic fusion occurs when selectively fusing the thoracic curve with a C modifier lumbar curve that completely deviates from the midline. Conversely, a true selective TL/L fusion occurs when the preoperative MT curve apex is completely off the midline (plumb line).

Lastly, a sagittal modifier based on the T5 – T12 sagittal Cobb measurement on the standing lateral radiograph is included in the classification. When the T5 – T12

Cobb measurement is less than $+10^0$, a "-" or hypokyphotic sagittal modifier is designated. When it is between +10 and $+40^0$, an "N" or normal kyphotic modifier is added. When it is ≥+40 , then a "+" or hyperkyphotic modifier is added. Thus, the Lenke Classification system combines the curve type along with the lumbar modifier and lastly the sagittal thoracic modifier for a complete curve classification.

3.7.1 Management

3.7.1 1 Assessment of Maturity

This would help the physician to explain to patient and family regarding the natural history of the disease and the available treatment option available at each level of maturity according to her curve progression i.e cobbs angle. This assesment of maturity is done clinically and radiologically.

3.7.1 2 Clinical Assessment

3.7.1 2.1 Tanner Staging

One of the important hallmarks of maturation is the development of secondary sexual characteristics, often classified by Tanner (Figure 2.9). The first stage of secondary breast development marks the beginning of puberty and usually takes place 1 year before the pubertal growth spurt. Girls typically experience their pubertal growth spurt between stages 2 and 3 of breast development and pubic hair development. The pubertal or Tanner stages are good measurements of maturity. Timing of menarche, the first menstrual period, can be used in girls but most often takes place 1 year after the growth spurt and is therefore always retrospective.

For girls it is based on their pubic hair and breast development to determine which groth stage they are in.

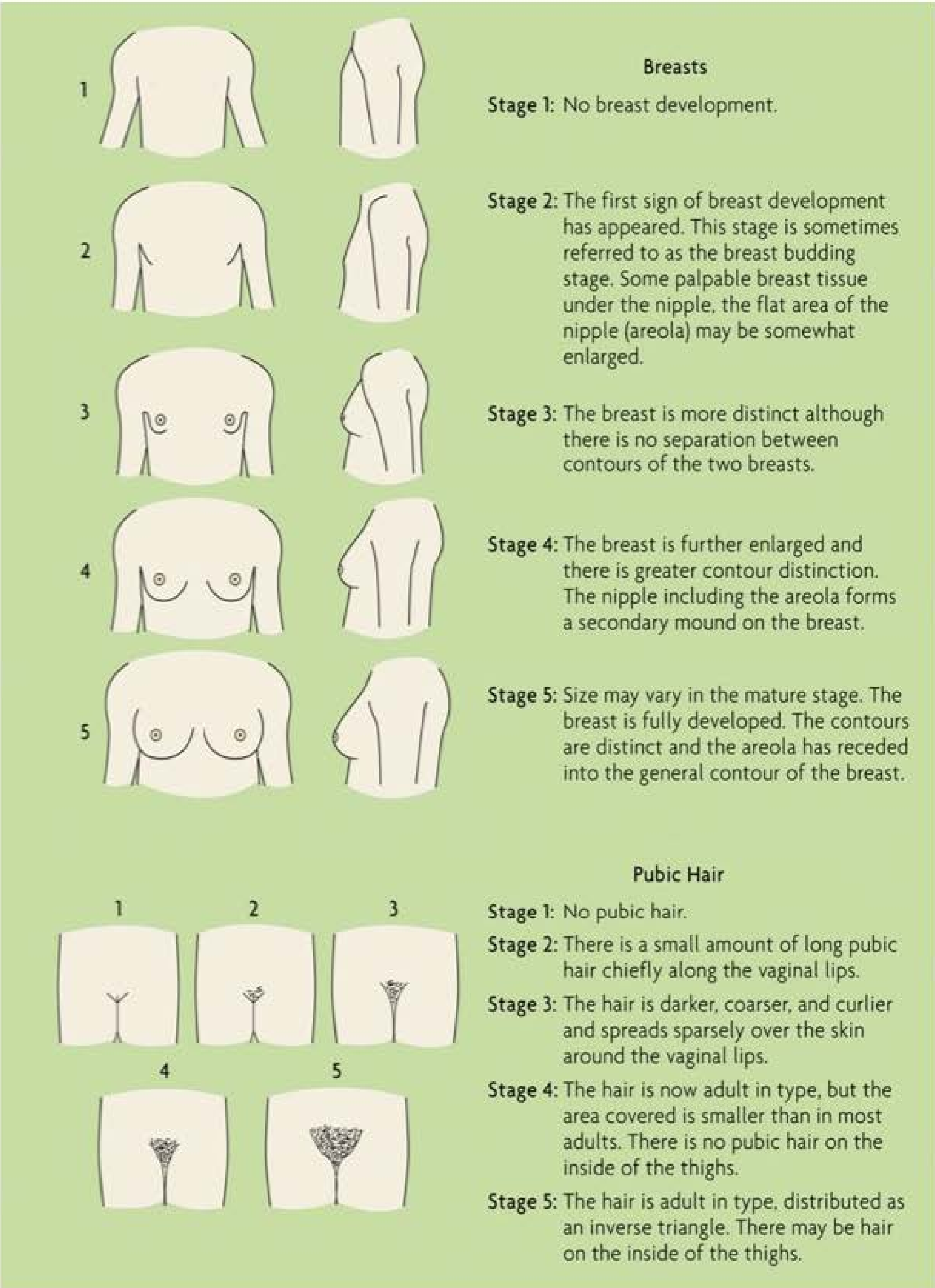
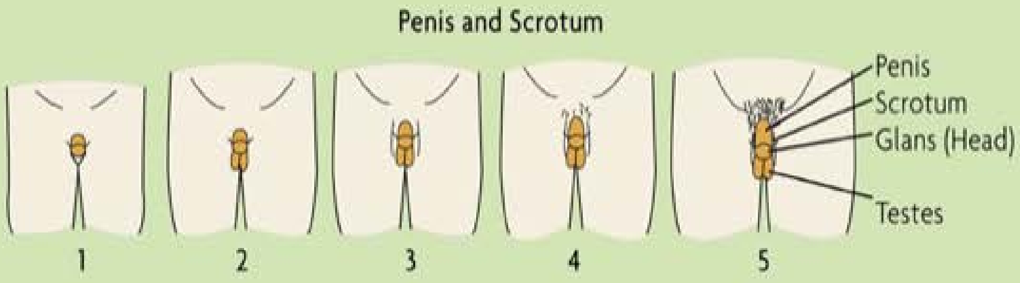


Figure 3.8 Tanner staging for girls

Note: Adapted from STUDYBLUE Flashcards – Exam 1

For boys it is based on their pubic hair and testicular development



Stage 1: The infantile state that persists from birth until puberty begins. During this time the genitalia increase slightly in overall size but there is little change in general appearance.

Stage 2: The scrotum has begun to enlarge, and there is some reddening and change in texture of the scrotal skin.

Stage 3: The penis has increased in length and there is a smaller increase in breadth. There has been further growth of the scrotum.

Stage 4: The length and breadth of the penis have increased further and the glans has developed. The scrotum is further enlarged and the scrotal skin has become darker.

Stage 5: The genitalia are adult in size and shape. The appearance of the genitalia may satisfy the criteria for one of these stages for a considerable time before the penis and scrotum are sufficiently developed to be classified as belonging to the next stage.

Stage 1: There is no true pubic hair, although there may be a fine velus over the pubes similar to that over other parts of the abdomen.

Stage 2: Sparse growth of lightly pigmented hair, which is usually straight or only slightly curled. This usually begins at either side of the base of the penis.

Stage 3: The hair spreads over the pubic symphysis and is considerably darker and coarser and usually more curled.

Stage 4: The hair is now adult in character but covers an area considerably smaller than in most adults. There is no spread to the medial surface of the thighs.

Stage 5: The hair is distributed in an inverse triangle as in the female. It has spread to the medial surface of the thighs but not elsewhere above the base of the triangle.

Figure 3.9 Tanner staging for boys

Note: Adapted from Tanner Stages Wikipedia

Menarche between stage 3 and 4 indicates end of growth spurt (Growth spurt is defined as increase in height of more than 6cm/year. It indicates a high risk of curve progression)

3.7.1 3 Radiological Assessment

a. Triradiate cartilage

b. Risser sign

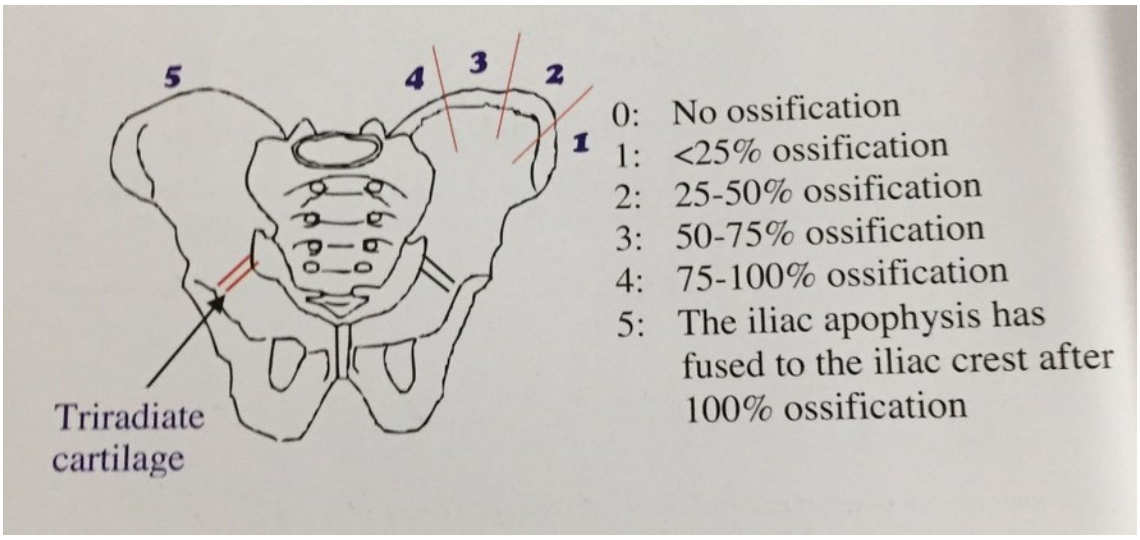


Figure 3.10 Riser sign and triradiate cartilage

Note: Adapted from Dimeglio A. Bonnel F, Canavese F. Normal Growth of the Spine and Thorax. In: Akbarnia B, Yazici M, Thompson G, editors. The Growing Spine: Springer Berlin Heidelberg; 2010. p. 13-42

Risser sign is defined by the amount of ossification present in the iliac apophysis from anterolaterally to posteromedially. It is an accepted prognostic sign in the evaluation of growth of patients with idiopathic scoliosis (Busscher and Veldhuizen, 2012).

Sanders *et al.* (2006) found the status of the triradiate cartilage (Figure 2.11) to be more predictive for the timing of the peak growth velocity of total body height, though it is only predictive whether the patient is before or after the pubertal growth spurt. Once the patient has closed triradiate cartilages, he or she is very likely past the pubertal growth spurt.

Table below explains how Growth Affects Progression of Scoliosis based on Four Different Growth Periods

Table 3.1 Progression of scoliosis and the growth periods

	Category	**Outcome**
I	Pre-menarche before Growth Spurt	Progression is dependent on the age and the growth velocity
II	Pre-menarche during Growth Spurt	Curve will progress very aggressively as the increment of height velocity is greatest at this point.
III	Post-menarche	Progession is approximately 5-10 degrees over a year.
IV	After attaining Risser 4 or skeletel maturity (determined radiographically)	Progression is approximately 1 degree a year for skeletal matured group (for thoracic curve more than 50 degrees and lumbar curve more than 30 degrees)

3.7.2 Treatment

Table 3.2 Management of idiopathic scoliosis based on curve magnitude and skeletel maturity

Cobb angle	I	II	III	IV
10° - 20°	Observe 6 monthly	Observe 4 monthly	Observe 6 monthly	Observe yearly (Risser 4) Discharge (skeletal maturity)
20° - 45°	Brace	Brace	Brace	Observe yearly (Risser 4) Observe two yearly (skeletal maturity)
$>45^\circ$	Brace	Open triradiate: Brace Close triradiate: PISF	PISF	PISF - 50° - 70° (Curves between 45° - 50°: Yearly observation - Risser 4/ Two yearly observation - skeletal maturity)
$>70^\circ$	Growing rod	Open triradiate: Growing rod Close triradiate: PISF	PISF	PISF

Note: PISF = Posterior Instrumental Spinal Fusion

3.7.2 1 Brace

Braces are external devices to maintain the position and prevent worsening of the curve in patients who are still growing (Group I, II, III). It can be used for curve apices between T6 and L3 (Schlenzka and Yrjönen, 2013). Indications to start bracing:

a. First time presentation $\geq 30^\circ$

b. Progression of the curve of a patient with a Cobb angle between 25° - 30°

c. Immature patient (at least 1 year of growth left)

d. Risser <3

e. Motivated patients / parents

(A progression is defined as a Cobb angle that progress more than 5 degrees in 2 consecutive X-rays i.e. a progression from 22° to 27°)